Initial geometry fluctuations
and
Triangular flow

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MIT

Glasma Workshop

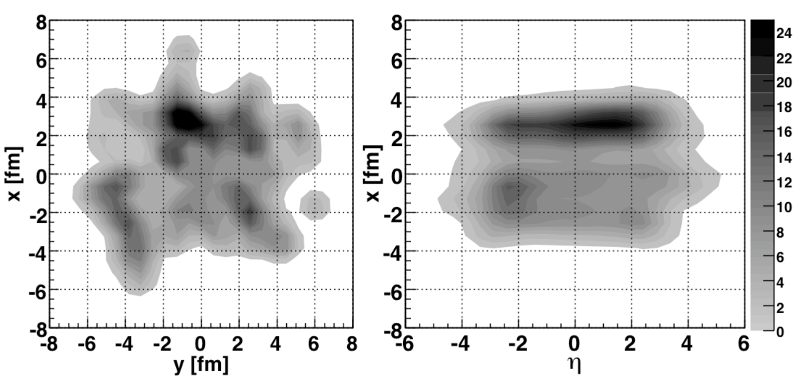
May 11, 2010

BA, G.Roland, arXiv:1003.0194 (PRC in press)

Two points

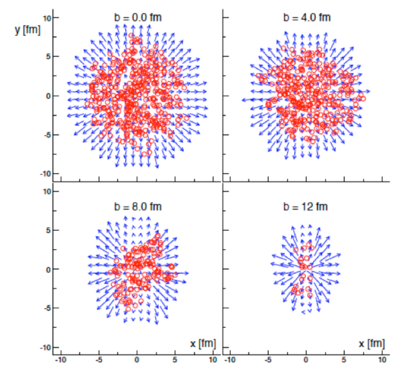
- Initial geometry fluctuations can explain the ridge and broad away side.

J. Takahashi et al.



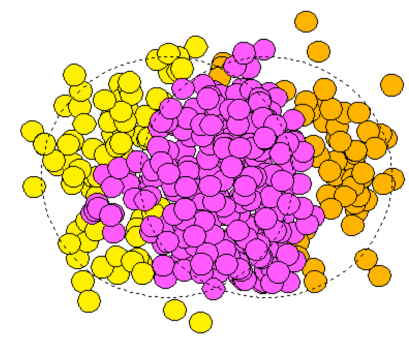
PRL 103, 242301 (2009)

P. Sorensen



arXiv:1002.4878

Glauber MC



arXiv:0805.4411

- Flow is the right language for these structures:

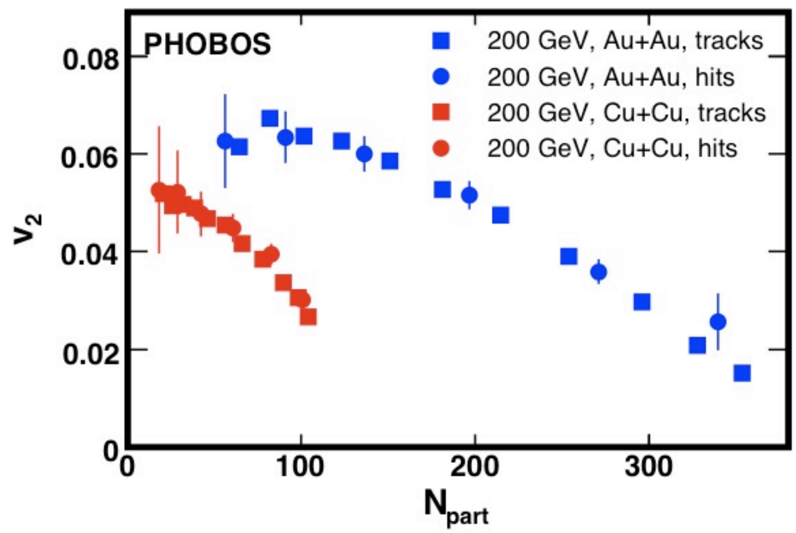
$$\varepsilon \Rightarrow v_2 \quad \text{Elliptic flow}$$

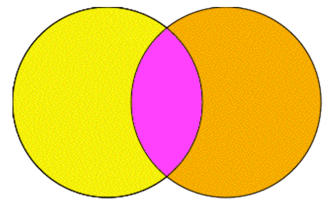
$$\varepsilon_3 \Rightarrow v_3 \quad \text{Triangular flow}$$

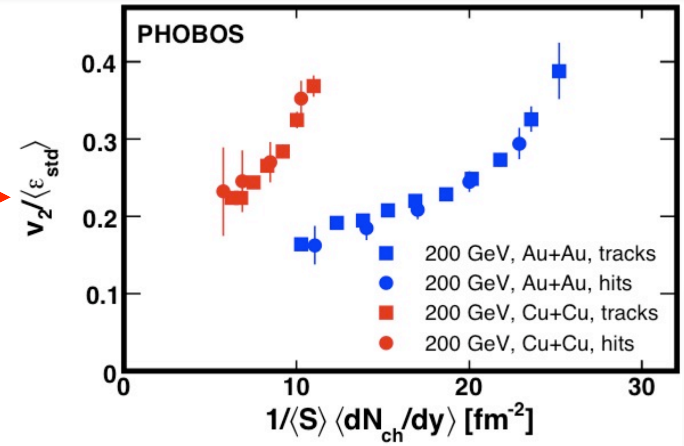
BA, G.Roland, arXiv:1003.0194 (PRC in press)

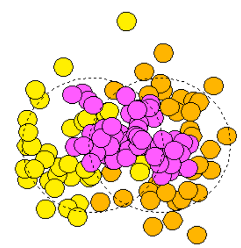
Initial Geometry Fluctuations I

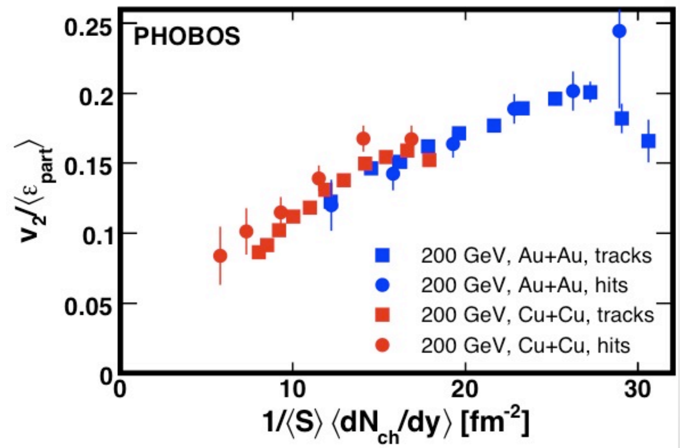
System size dependence
of elliptic flow









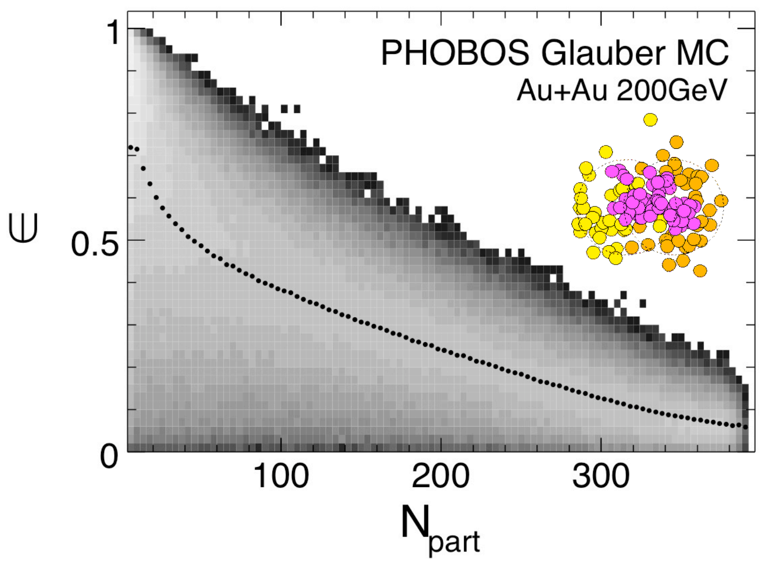


Participant eccentricity reconciles
elliptic flow for Cu+Cu and Au+Au collisions.

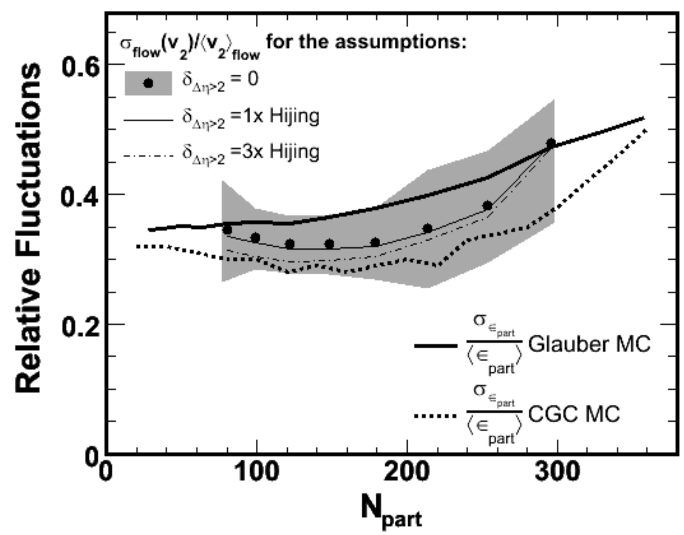
PHOBOS PRL 98, 242302 (2007)

Initial Geometry Fluctuations II

Eccentricity fluctuations



Elliptic flow fluctuations



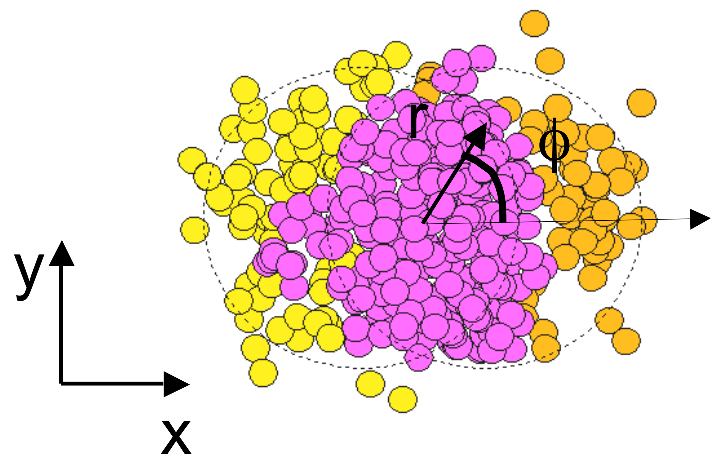
Observed elliptic flow fluctuations confirm large fluctuations in the initial collision geometry.

PHOBOS PRL 104, 142301 (2010)
PHOBOS PRC81, 034915 (2010)

Participant triangularity

Triangular anisotropy in initial geometry can be quantified by “participant triangularity” analogous to participant eccentricity.

$$\varepsilon = \frac{\sqrt{\left(\sigma_y^2 - \sigma_x^2\right)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$



$$\varepsilon = \frac{\sqrt{\left\langle\left(r^2\cos(2\phi)\right)\right\rangle^2 + \left\langle\left(r^2\sin(2\phi)\right)\right\rangle^2}}{\left\langle r^2\right\rangle}$$

$$\varepsilon_3 = \frac{\sqrt{\left\langle\left(r^2\cos(3\phi)\right)\right\rangle^2 + \left\langle\left(r^2\sin(3\phi)\right)\right\rangle^2}}{\left\langle r^2\right\rangle}$$

BA, G.Roland, arXiv:1003.0194 (PRC in press)

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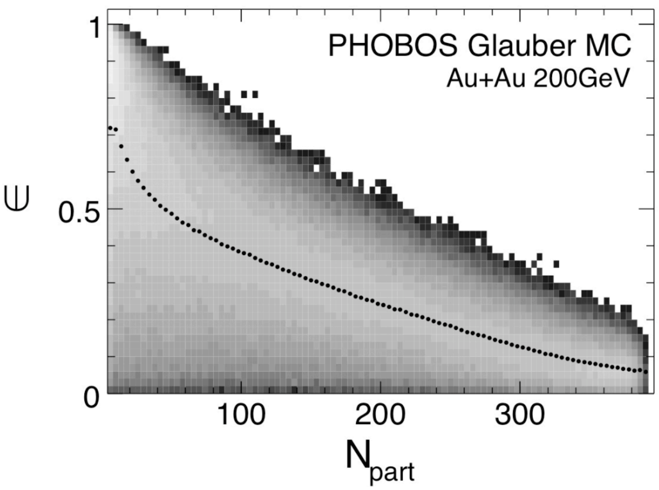
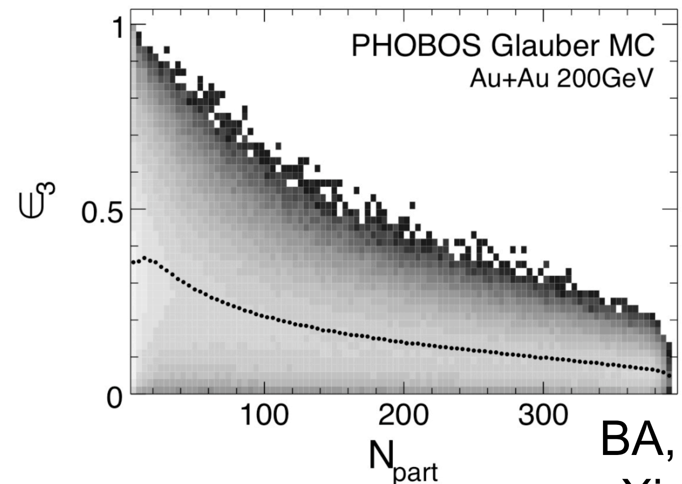
$$\varepsilon = \frac{\sqrt{\left\langle \left(r^2 \cos(2\phi) \right) \right\rangle^2 + \left\langle \left(r^2 \sin(2\phi) \right) \right\rangle^2}}{\left\langle r^2 \right\rangle}$$

$$\varepsilon_3 = \frac{\sqrt{\left\langle \left(r^2 \cos(3\phi) \right) \right\rangle^2 + \left\langle \left(r^2 \sin(3\phi) \right) \right\rangle^2}}{\left\langle r^2 \right\rangle}$$





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Participant triangularity

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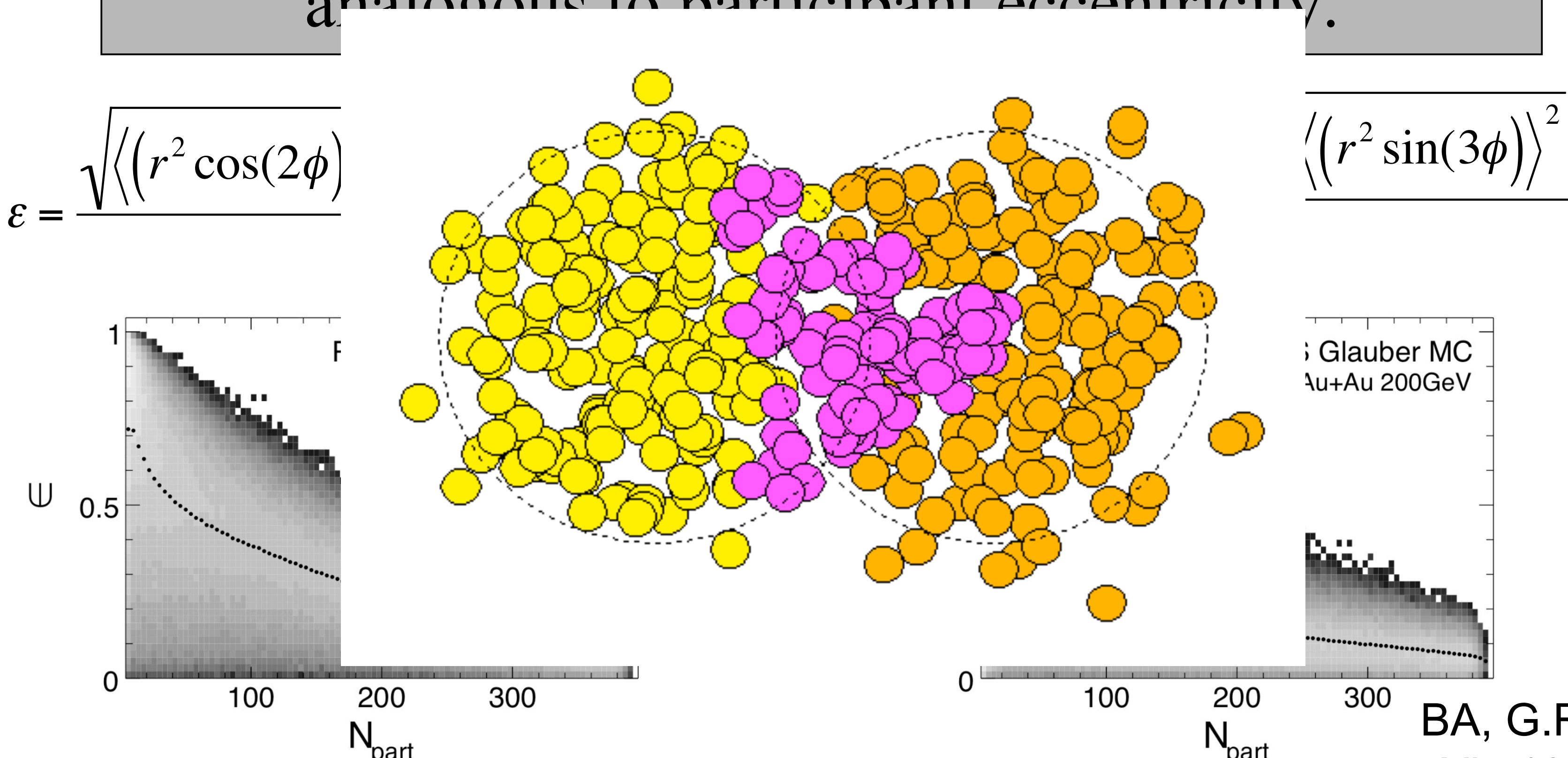
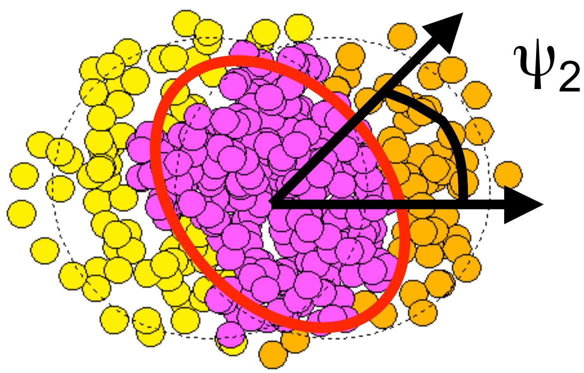
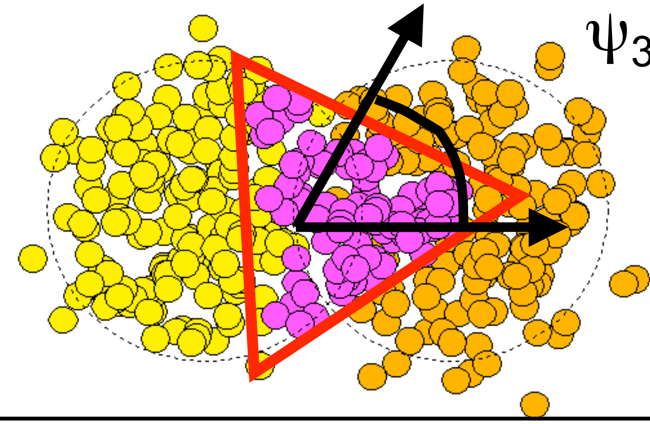
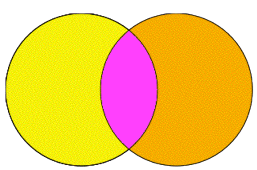


BA, G.Roland,
arXiv:1003.0194
(PRC in press)

Triangular flow



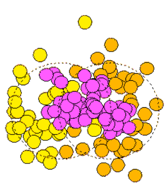




$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n(\phi - \psi_R)\right)\right)$$

$$v_2 = \left\langle \cos\left(2(\phi - \psi_R)\right)\right\rangle$$

$$v_3 = 0$$



$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n(\phi - \psi_n)\right)\right)$$

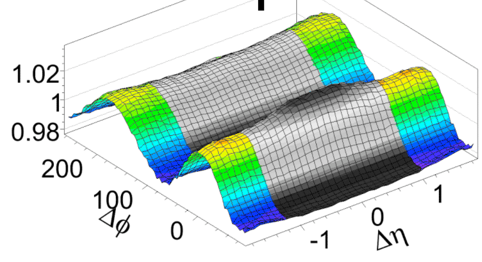
$$v_2 = \left\langle \cos\left(2(\phi - \psi_2)\right)\right\rangle$$

$$v_3 = \left\langle \cos\left(3(\phi - \psi_3)\right)\right\rangle$$

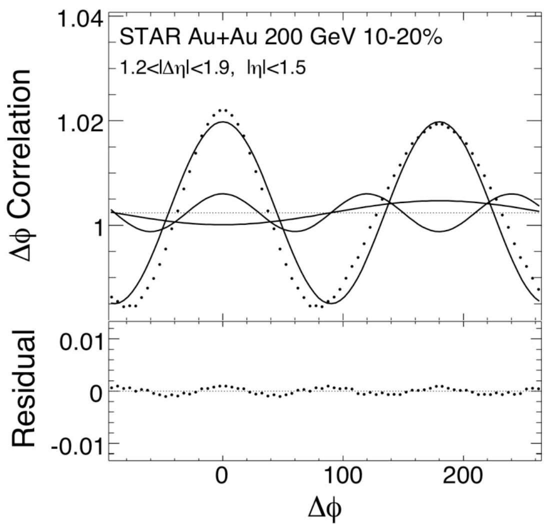
BA, G.Roland,
arXiv:1003.0194
(PRC in press)

Correlations at large Δη

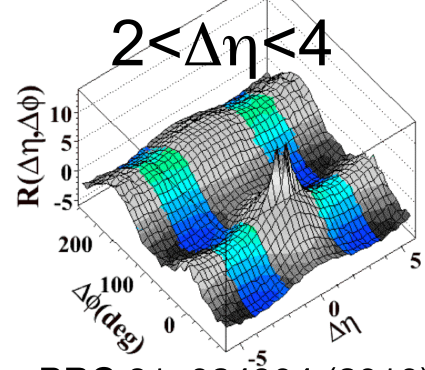
STAR inclusive
$1.2<\Delta\eta<1.9$



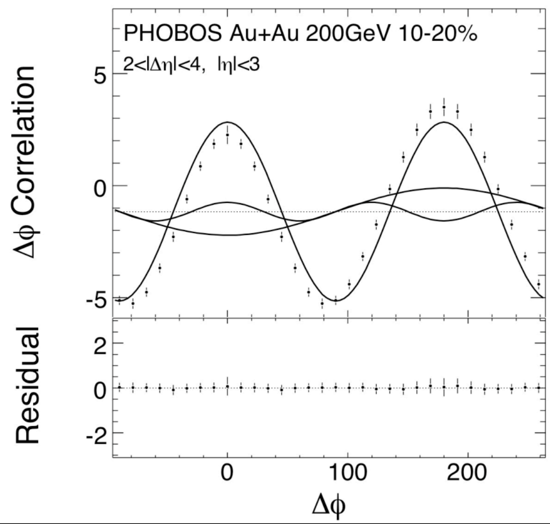
arXiv:0806.0513



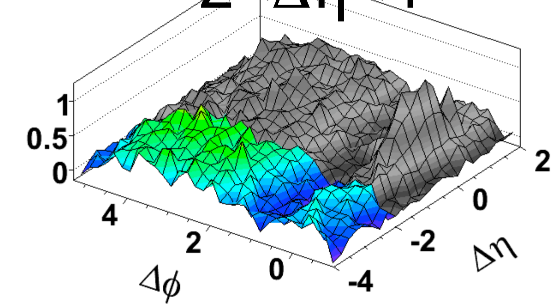
PHOBOS inclusive
$2<\Delta\eta<4$



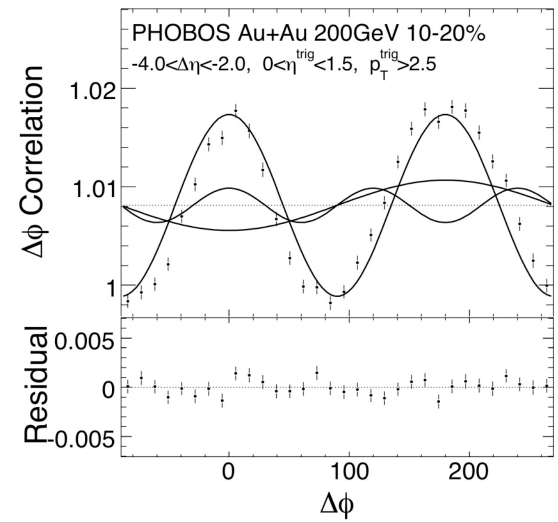
PRC 81, 024904 (2010)



PHOBOS p_T^{trig}>2GeV
$2<\Delta\eta<4$



PRL 104, 06230 (2010)

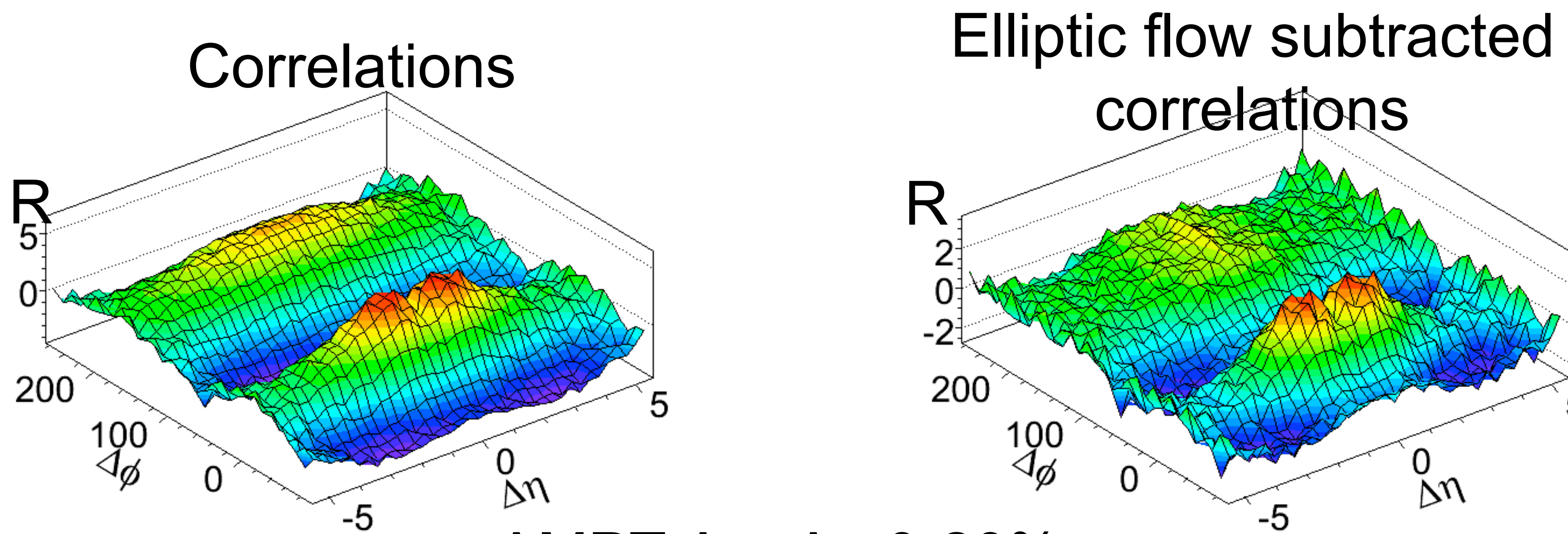


Long range correlations are well described by 3 Fourier Components.

BA, G.Roland, arXiv:1003.0194 (PRC in press)

AMPT Model

AMPT model: Glauber initial conditions, collective flow

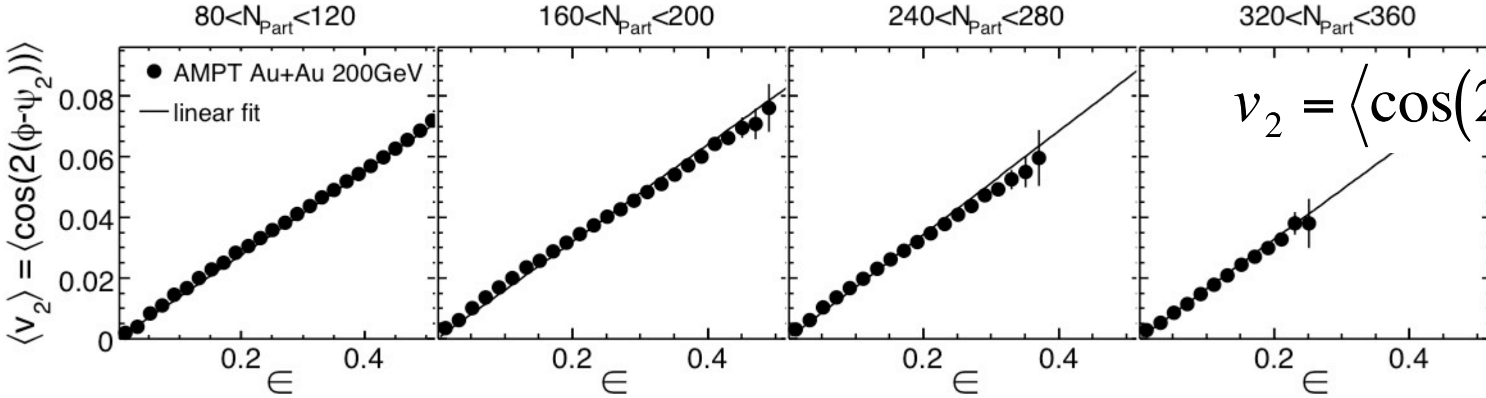


AMPT Au+Au 0-20%

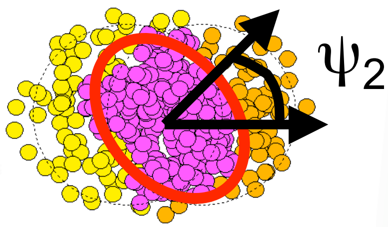
AMPT model also produces similar correlation structures that extend out to long range in $\Delta\eta$.

Lin et. al. PRC72, 064901 (2005)
Ma et. Al. PLB641 362 (2006)

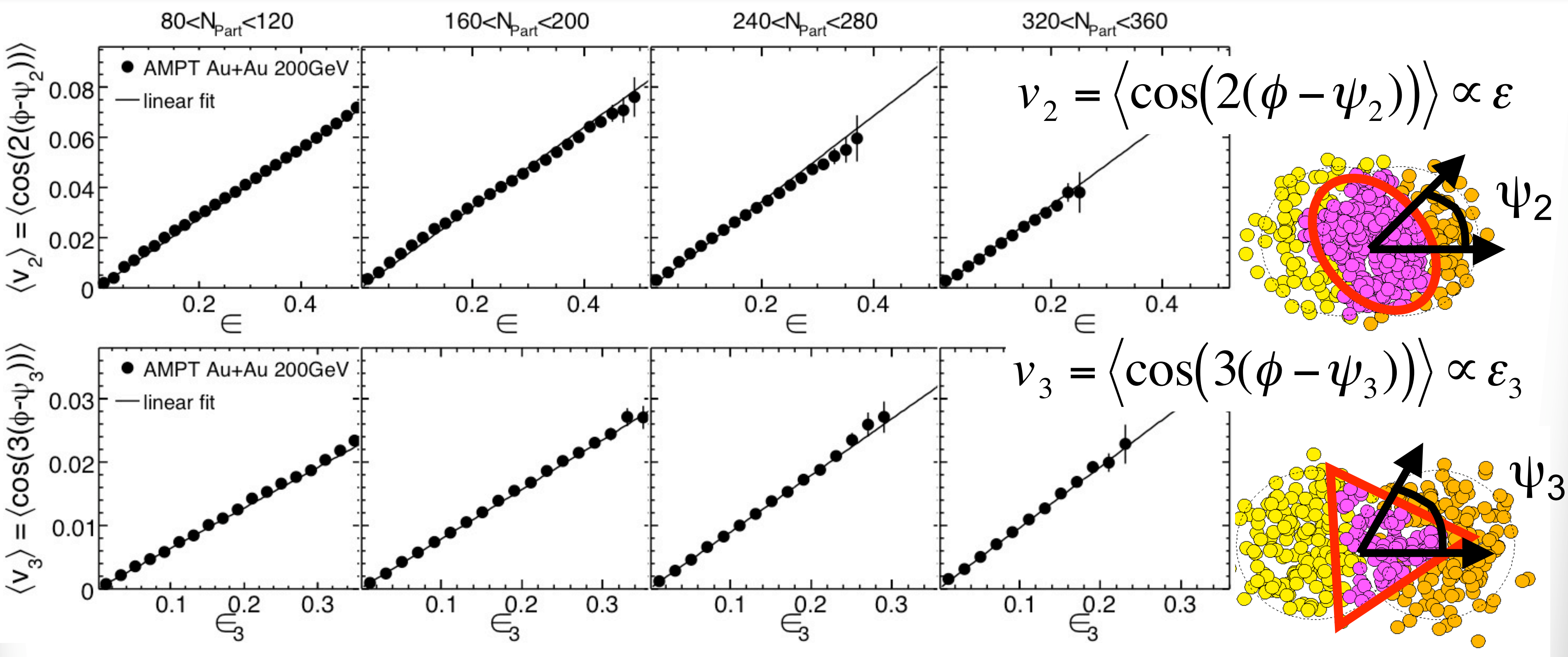
Elliptic flow in AMPT



$$v_2 = \left\langle \cos\left(2(\phi - \psi_2)\right) \right\rangle \propto \varepsilon$$



Triangular flow in AMPT

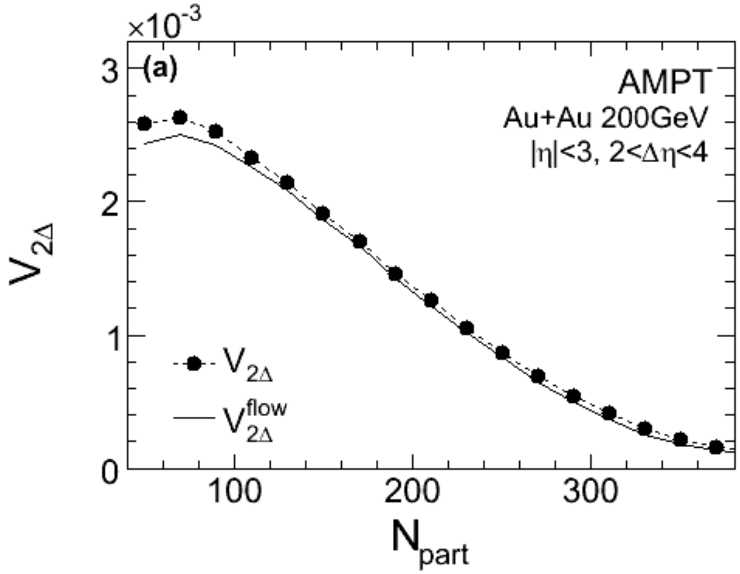


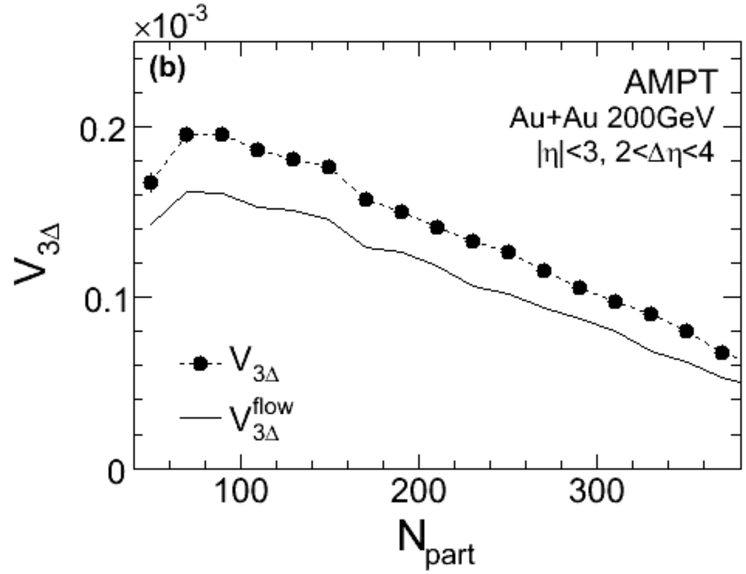
Triangularity leads to triangular flow in AMPT.

BA, G.Roland,
arXiv:1003.0194
(PRC in press)

Flow and correlations in AMPT

$$\frac{dN}{d\Delta\phi} = \frac{N}{2\pi}\left(1 + \sum 2\mathbf{V}_{n\Delta}\cos\left(n\Delta\phi\right)\right) \qquad \mathbf{V}_{\mathbf{n}\Delta}^{\mathbf{flow}} \sim \int v_n(\eta) \times v_n(\eta + \Delta\eta)\, d\eta$$





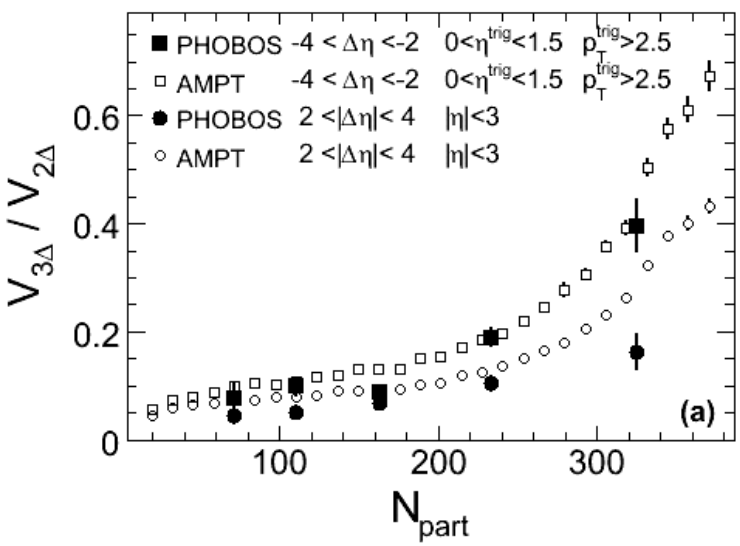
$$\mathbf{V}_{\mathbf{3}\Delta} = \left\langle \cos\left(3(\phi_1 - \phi_2)\right)\right\rangle$$

$$\mathbf{V}_{\mathbf{3}\Delta}^{\mathbf{flow}} = \left\langle \cos\left(3(\phi_1 - \psi_3)\right)\right\rangle\left\langle \cos\left(3(\phi_2 - \psi_3)\right)\right\rangle$$

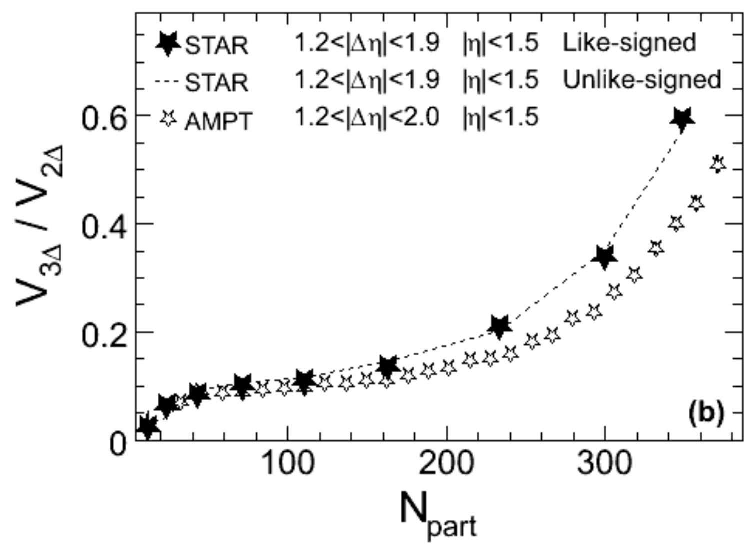
BA, G.Roland,
arXiv:1003.0194
(PRC in press)

Triangular flow in data

PHOBOS



STAR



The ratio of triangular flow to elliptic flow qualitatively agree between data and AMPT.

STAR arXiv:0806.0513

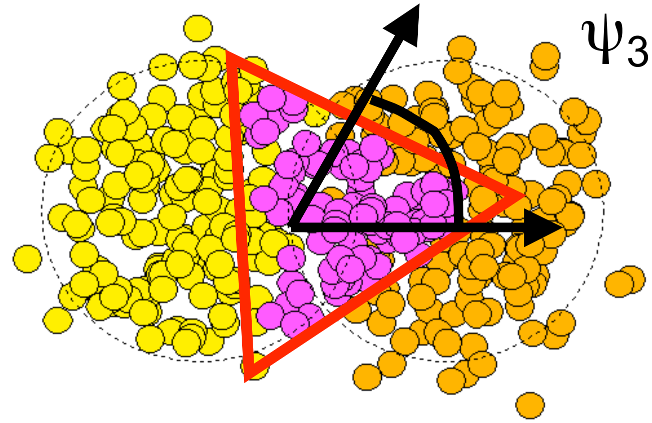
PHOBOS PRC 81, 024904 (2010)

PHOBOS PRL 104, 06230 (2010)

BA, G.Roland, arXiv:1003.0194 (PRC in press)

Summary

- Fluctuations in MC Glauber leads to finite "participant triangularity."
- In AMPT model, large triangular flow signal observed correlated with initial triangularity:

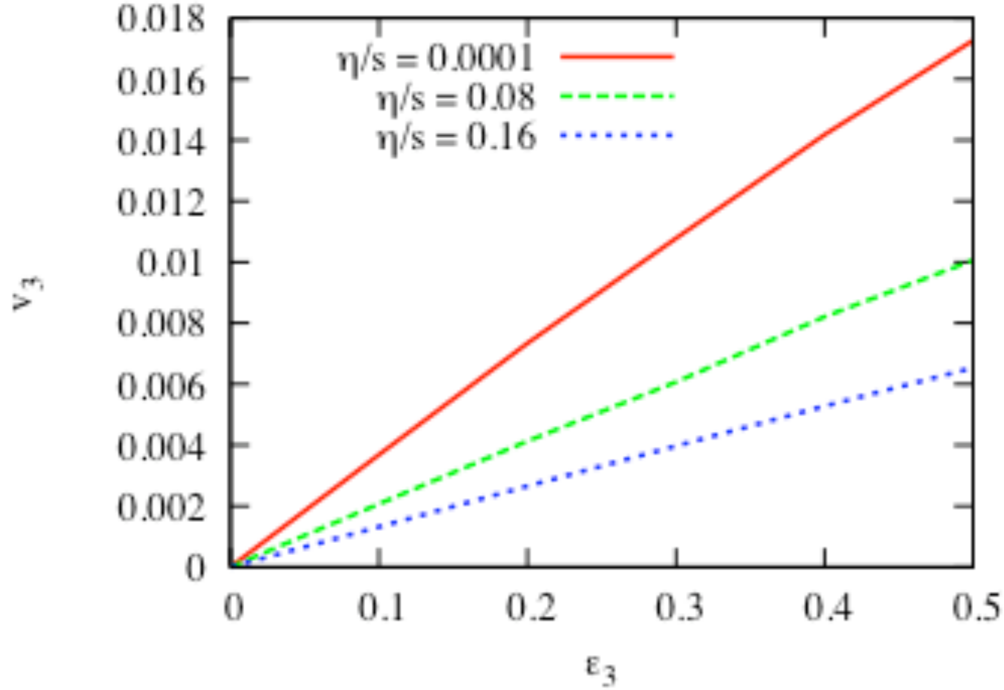


$$v_3 = \langle \cos(3(\phi - \psi_3)) \rangle \propto \varepsilon_3$$

- Ridge and broad away side in AMPT have dominant contribution from triangular flow.
- Fourier decomposition of long range azimuthal correlations in AMPT and data show qualitative agreement as a function of centrality and momentum.

BA, G.Roland, arXiv:1003.0194 (PRC in press)

Future



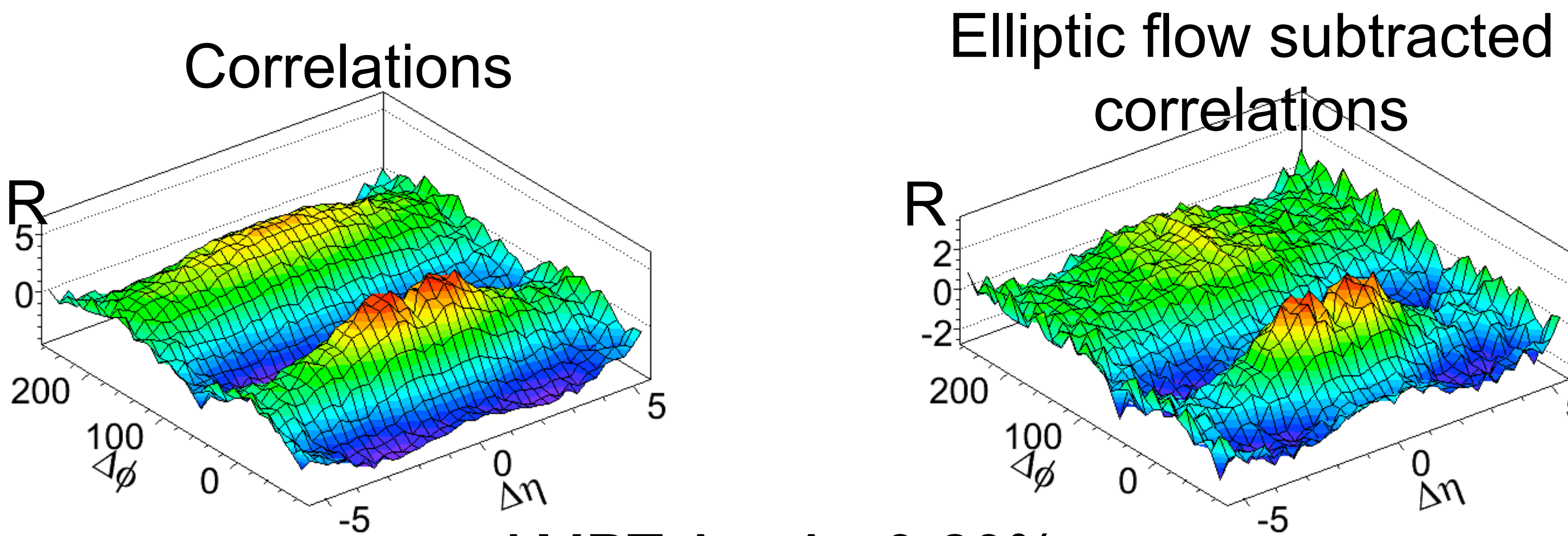
Triangular flow is a new handle on the initial geometry and the hydrodynamic expansion of the medium.

Luzum, Ollitrault Private communication

Backups

AMPT Model

AMPT model: Glauber initial conditions, collective flow



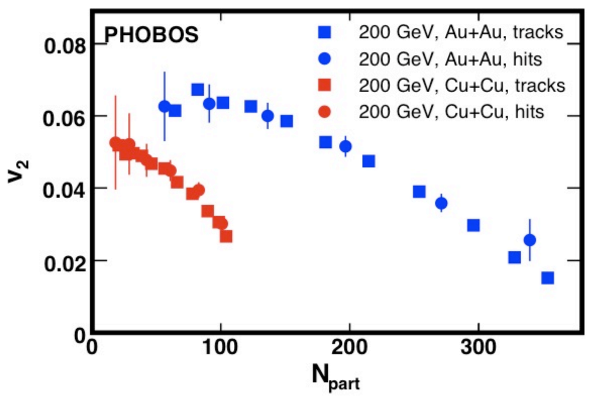
AMPT Au+Au 0-20%

AMPT model also produces similar correlation structures that extend out to long range in $\Delta\eta$.

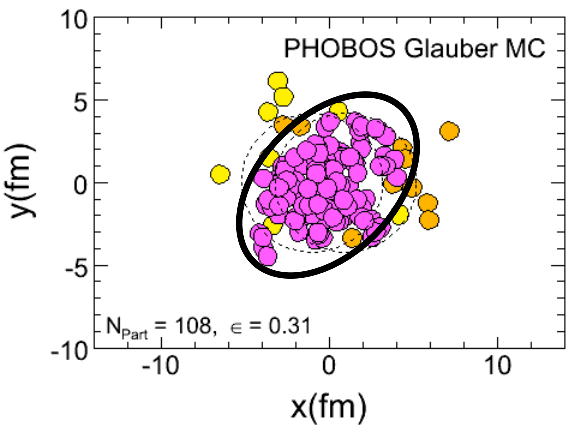
Lin et. al. nucl-th/0411110

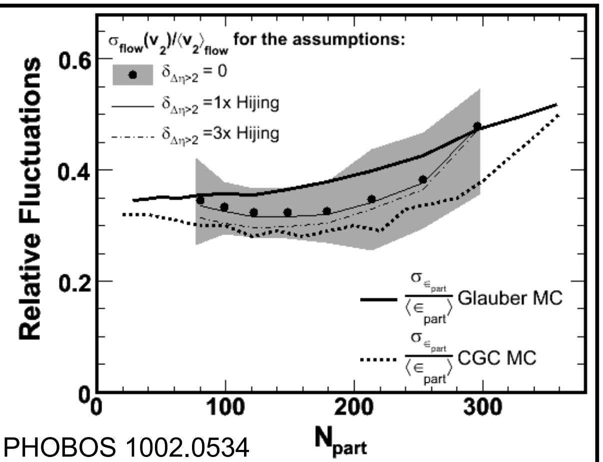
Initial geometry fluctuations

A consistent picture

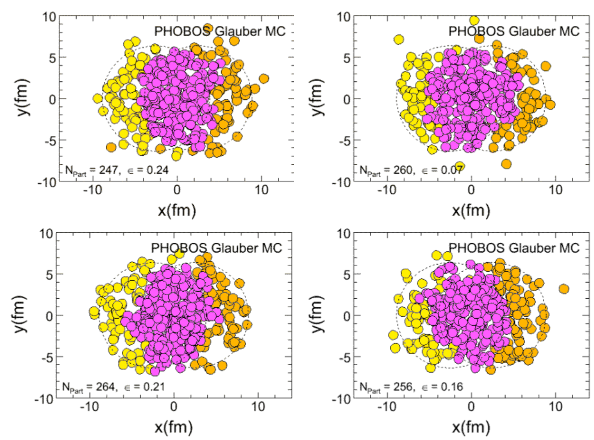


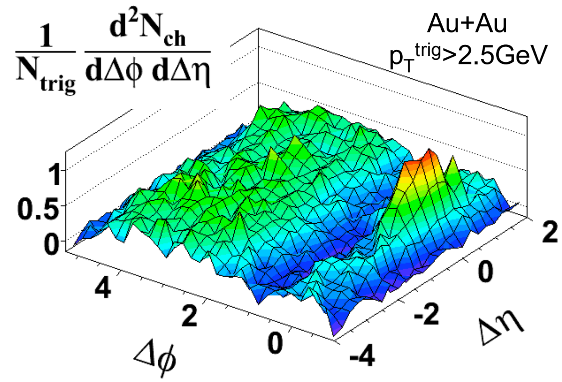
PHOBOS nucl-ex/0610037



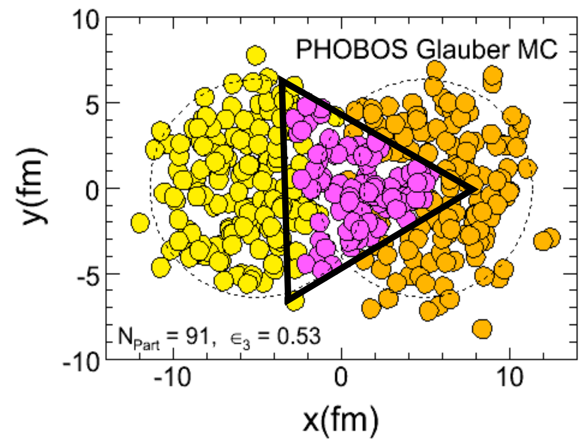


PHOBOS 1002.0534



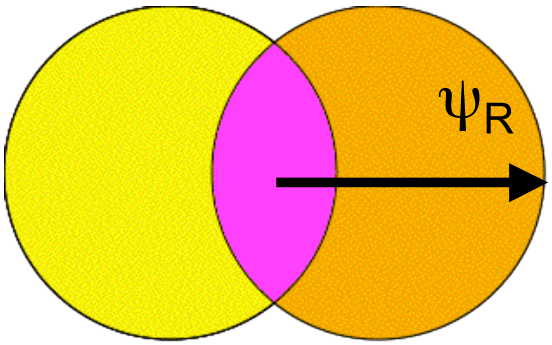


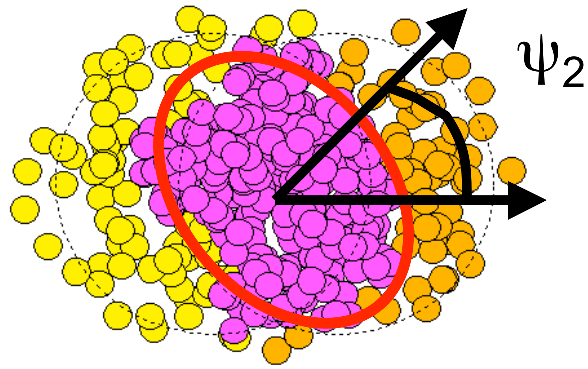
PHOBOS 0903.2811



1003.0194

Two different pictures





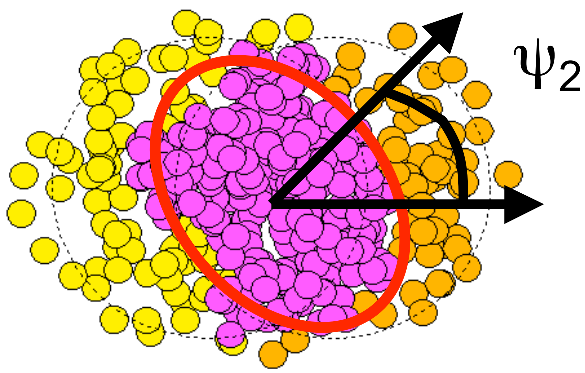
$$\frac{\mathrm{d}N}{\mathrm{d}\phi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n(\phi - \psi_R)\right)\right)$$

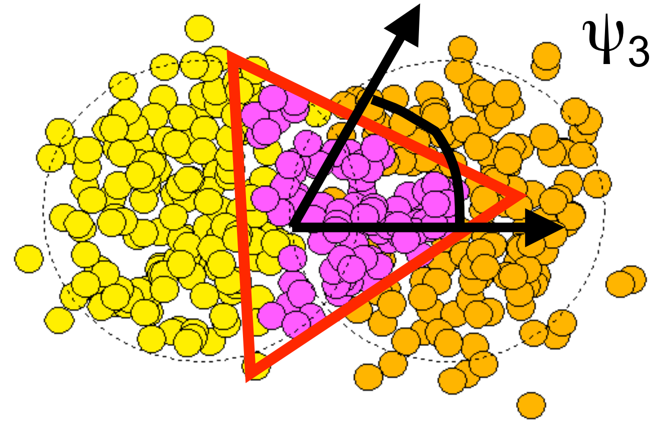
$$\frac{\mathrm{d}N}{\mathrm{d}\phi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n(\phi - \psi_n)\right)\right)$$

$$v_2 = \left\langle \cos\left(2(\phi - \psi_R)\right) \right\rangle$$

$$v_2 = \left\langle \cos\left(2(\phi - \psi_2)\right) \right\rangle$$

Triangular flow





$$\psi_2 = \frac{\operatorname{atan2}\left(\left\langle r^2 \sin\left(2\phi_{\text{part}}\right)\right\rangle, \left\langle r^2 \cos\left(2\phi_{\text{part}}\right)\right\rangle\right) + \pi}{2}$$

$$\psi_3 = \frac{\operatorname{atan2}\left(\left\langle r^2 \sin\left(3\phi_{\text{part}}\right)\right\rangle, \left\langle r^2 \cos\left(3\phi_{\text{part}}\right)\right\rangle\right) + \pi}{3}$$

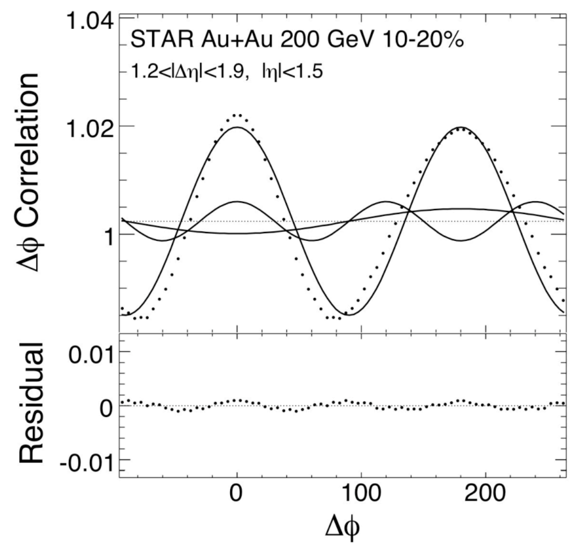
1003.0194

Phases

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n(\phi - \psi_n)\right)\right)$$

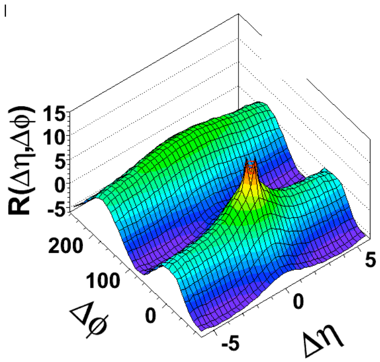
$$= \frac{N}{2\pi}\left(1 + \ldots + 2v_2 \cos\left(2(\phi - \psi_2)\right) + 2v_3 \cos\left(3(\phi - \psi_3)\right) + \ldots\right)$$

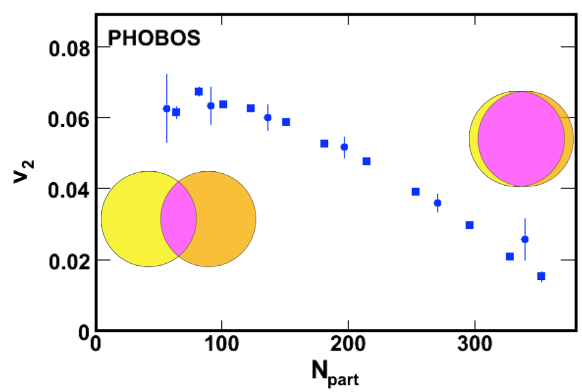
$$\frac{dN^{\text{pairs}}}{d\Delta\phi} = \frac{N^{\text{pairs}}}{2\pi}\left(1 + \ldots + 2v_2^2 \cos\left(2\Delta\phi\right) + 2v_3^2 \cos\left(3\Delta\phi\right) + \ldots\right)$$

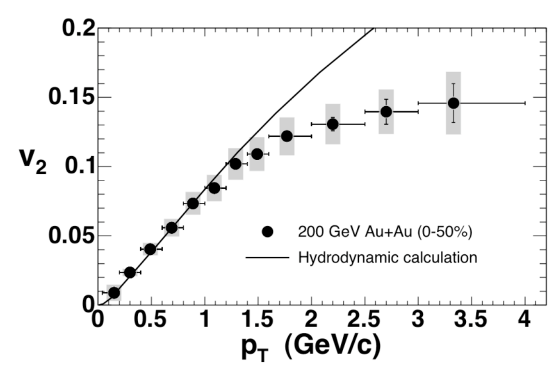


Second Fourier coefficient

- Why do we believe it is collective flow?
  - Large!
  - Present at large $\Delta\eta$: early times
  - Connection to initial geometry
    - i.e. centrality dependence
  - p_T dependence
  - Also $v_2\{4\}$, v_2 fluctuations and $v_2^2(\eta_1,\eta_2)$







Third Fourier coefficient

- Why should we believe it is collective flow?
  - Large!
  - Present at large $\Delta\eta$: early times
  - Connection to initial geometry
    - i.e. centrality dependence
  - p_T dependence
  - Also three particle correlations